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# *Waste management practices of the United States Antarctic Program*

Sherwood C. Reed and Robert S. Sletten





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The United States operates research facilities in Antarctica, at coastal locations, inland sites, and on the interior snowfield. This report documents the results of 1988 investigations and evaluations of present waste management practices at these stations and recommends future action. In addition to liquid and solid waste management, the report discusses related water supply issues.


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## PREFACE

This report was prepared by Sherwood C. Reed and Robert S. Sletten, Environmental Engineers in the Civil and Geotechnical Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this effort was provided by the Division of Polar Programs—Operations, U.S. National Science Foundation, Washington, D.C.

This report was technically reviewed by Dr. Malcolm Mellor and Wayne Tobiasson, both from CRREL.

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## EXECUTIVE SUMMARY

This report presents results of a study undertaken to evaluate the waste management practices of the United States Antarctic Program. The study is based on a review of reports and other literature, contact with other organizations and individuals, and field observations made during January 1988. The principal focus was on liquid and solid waste management at McMurdo Station and at the activities supported from McMurdo.

The present wastewater system at McMurdo involves maceration of human wastes and garbage, dilution with waste brine from the water distillation plant and direct discharge to the waters of McMurdo Sound. Adverse environmental impacts resulting from operations of this type cannot be documented or demonstrated. Suggestions for more advanced forms of wastewater treatment are not justified in that minimal environmental benefits would be realized. The present practice should be continued, but improved with the construction of a submerged outfall pipe extending into McMurdo Sound.

A study should be undertaken to consider the beneficial use of the warm brine now discharged with the wastewater. Uses could include heat recovery, fire protection or snow melting.

Wastewater discharge to the snowpack as practiced at Williams Field and Pole Station is safe, effective, environmentally compatible and should be continued. A study should be undertaken to define the wastewater containment zone in the snowpack to assist in future operations and in the design of replacement systems.

The management practices for combustible solid wastes at McMurdo are reliable and effective and should be continued. The open burning for volume reduction at Fortress Rock is not comparable to the smoldering burns that used to occur at open dumps in the U.S. The waste fuel oil used at McMurdo produces a very hot, "quick" fire, with minimal losses of particulate matter. The atmospheric impact of this periodic burning is probably less than the engine exhausts and dust from routine activities at McMurdo Station. The alternatives (i.e., incineration, retrograde of baled wastes, etc.) would provide minimal environmental benefits at a very high cost and complexity but with a relatively low reliability. Scott Base, for example, has an emission-controlled incinerator but still brings large combustible items to the Fortress Rock site for open burning. As a result, the incinerator becomes more of a symbol than an effective device for environmental protection.

Current practice requires the packaging and retrograde of scrap metal. This approach was followed during the 1987–88 season but is very labor intensive and should be reconsidered. The managed disposal of clean scrap metal to the deep waters (>100 fathoms) of McMurdo Sound will not cause any adverse environmental impact and is allowed by the Treaty. This does *not* mean the restoration of the former practice of disposal of solid wastes to the surface of the annual sea ice in hopes that it would be carried away during breakup. Suggestions are made in the text of this report for the deep-water disposal of these materials in an environmentally compatible manner.

Past waste disposal activities have resulted in the accumulation of scrap metal, debris, ice and fill material along a portion of the McMurdo shoreline. At this point it is

not practical to attempt the removal of scrap metal and other debris from the mass of material present. Current efforts to cover this entire area with fill should be continued until there is no visible evidence of waste materials. The mass should thereafter remain in the frozen state because of the low temperature and the protective fill and should therefore have no adverse environmental impact.

It is clear that the U.S. presence in Antarctica has undergone a very significant transition during the past decade. The former ad-hoc expeditionary facilities and attitudes by some personnel have given way to the modern community with all utility services that now exists on the shores of McMurdo Sound. Concurrent with the development of that community is the commitment by NSF and all personnel involved to proper operation and maintenance and to environmental protection, and to the cleanup of the residuals from the expeditionary years. Many of the criticisms of U.S. operations that appear in the public press are due to the last vestiges of these residuals or to unfounded speculations regarding the environmental impact of current waste management practices.

**CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT**

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

| Multiply | By | To obtain |
|---|---|---|
| inch | 25.4 | millimeter |
| foot | 0.3048 | meter |
| yard | 0.9144 | meter |
| mile (U.S. survey) | 1609.347 | meter |
| mile (U.S. nautical) | 1852.000 | meter |
| fathom | 1.8288 | meter |
| foot$^2$ | 0.09290304 | meter$^2$ |
| foot$^3$ | 0.02831685 | meter$^3$ |
| gallon (U.S. liquid) | 0.003785412 | meter$^3$ |
| gallon/day | 0.00000004381264 | meter$^3$/second |
| pound | 0.4535924 | kilogram |
| ton (short) | 907.1847 | kilogram |
| pound/foot$^3$ | 16.01846 | kilogram/meter$^3$ |
| degrees Fahrenheit | T°C = (T°F −32)/1.8 | degrees Celsius |

# Waste Management Practices of the United States Antarctic Program

SHERWOOD C. REED AND ROBERT S. SLETTEN

## INTRODUCTION

This study was conducted at the request of the Polar Operations Section, Division of Polar Programs of the National Science Foundation (NSF), under the interagency agreement between NSF and the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL).

The purpose of this effort was to evaluate the waste management practices of the United States Antarctic Program (USAP), in the context of applicable laws, regulations, agreements and environmental practices. The study considered McMurdo Station and the outlying stations and camps supported from McMurdo. These included Williams Field, Pole Station and operations at small temporary field camps. Figures 1 and 2 show the location of the major facilities.

The study considered the production, handling, storage and recycle or disposal of both liquid and solid wastes at these stations and camps. Since the volume of water that is produced and used influences liquid waste management practices, the water supply operations are also discussed in this report.

The information contained in this report is based, in part, on literature reviews and contacts with organizations and individuals with experience in Antarctica (the assistance of the US Naval Civil Engineering Laboratory in Port Hueneme, California, is especially appreciated). Field observations made in Antarctica during January 1988, by the senior author of this report, provide the basis for the evaluation of current practices and recommendations for future action.

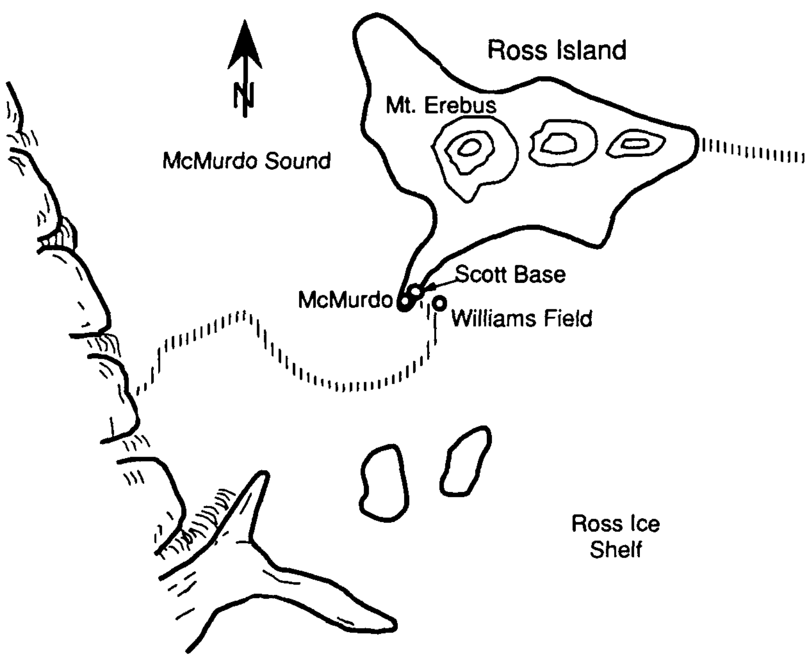


*Figure 1. Facilities in the vicinity of McMurdo Station.*

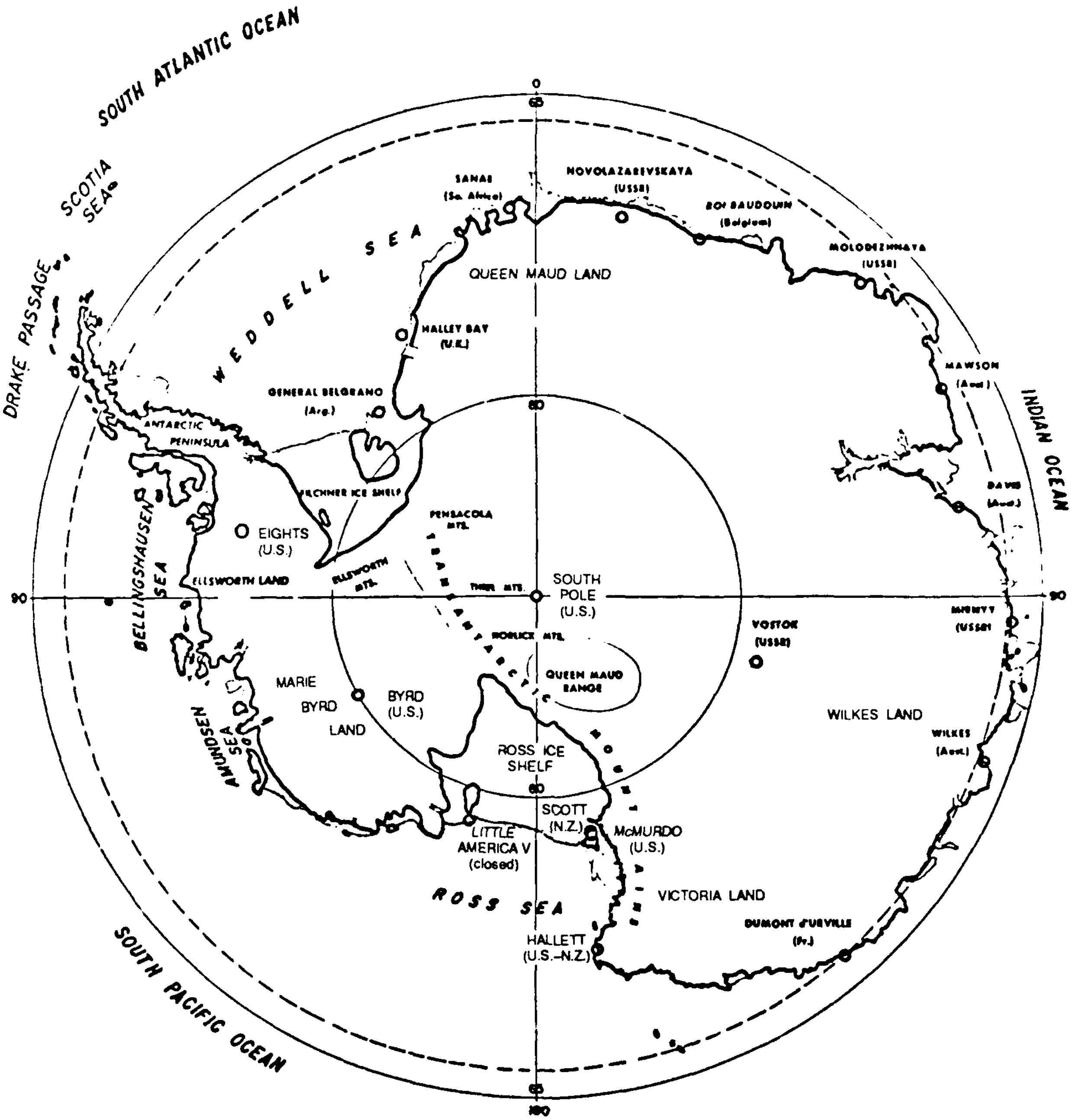


*Figure 2. Location of the major USAP activities in Antarctica.*

## HISTORICAL DEVELOPMENT

The current U.S. presence in Antarctica dates from 1955 when preparations were made for the International Geophysical Year (IGY). McMurdo Station was established as the logistical staging area to support expeditions and activities elsewhere on the continent. McMurdo Station has been continuously occupied since that time and has become the principal terminal and science center for the USAP, with a population ranging from about 200 to 1000, depending on the season.

Also in the McMurdo area are Scott Base, the New Zealand station, a temporary runway established on the annual sea ice for use by wheeled aircraft during the early part of each operational season, and Williams Field, a snow runway for ski-equipped aircraft located on the snow pack of the adjacent Ross Ice Shelf. The ice runway is reestablished annually, and Williams Field is relocated every three to five years because of the lateral movement of the Ross Ice Shelf. These air operations support temporary and semi-permanent activities at the more remote locations on the continent. That support function continues at the present time, but the only permanently occupied

U.S. operation in the interior is the station at the South Pole.

All of the early facilities provided adequate shelter for personnel, but little else (Coffin 1961, Clark and Groff 1962, and Cosenza 1966). A piped water supply was generally not provided, and the source in all cases was melted snow, so there were severe restrictions on water use by the personnel. Wastewater management was also very primitive. Washwaters were discharged to the adjacent ground surface, fecal matter was collected in drums serving the latrines and allowed to freeze, urine was either discharged to the ground surface or collected and frozen in "U" barrels (cut-off 55-gal. drums). All of these waste materials, along with the ash from the burned trash and garbage, scrap metal, unserviceable equipment, etc., were placed on the adjacent sea ice with the expectation that the annual ice breakup would carry them away and allow them to sink in the deep waters of McMurdo Sound. At some point, this disposal occurred too close to shore or the load was too heavy so the annual ice grounded instead of floating away and the unserviceable equipment and scrap metal became, for several years, an apparently permanent fixture on the McMurdo Station shoreline.

These approaches to waste management were not due to a willful disregard of environmental concerns, but rather were the result of limited facilities, equipment and manpower during the "expeditionary" phase of U.S. operations in Antarctica. However, this expeditionary phase lasted for many years, and undoubtedly had an effect on the attitude and commitment of the individuals involved. The senior author visited McMurdo, Williams Field, Byrd Station and Pole Station in 1969, and the junior author wintered over at McMurdo in 1965, so both can speak from direct experience on this issue.

The support staff during this early period were hard-working, dedicated groups trying to maintain the facilities with minimal resources and with limited continuity of experience due to the relatively rapid personnel turnover. The expeditionary character of the operations tended to encourage a short-term, problem-solving attitude that attempted to get through *this* year as well as possible but with limited concern for *next* year or the years thereafter. Such an ad hoc approach to waste management is obviously not the best way to ensure environmental protection.

During this same period, however, very significant research efforts were conducted by the Naval Civil Engineering Laboratory, CRREL, and others that developed the necessary technology (i.e., utility networks, structures, foundation systems, etc.) for design and construction of permanent facilities in polar regions. Even more important has been the commitment of the U.S. Congress and the National Science Foundation to a long-term program to upgrade the U.S. facilities in Antarctica.

A major effort was the construction of a new dome-covered station at the South Pole in the early 70s. A concurrent and continuing effort was aimed at replacing the "temporary" structures at McMurdo with permanent buildings and utility networks. As of 1988, very few of the original structures remain. They have been replaced with modern, thermally efficient buildings, all serviced by water, sewer and electrical utility lines. Several new dormitories and a new science building are major components in the current construction program. In effect, this effort has converted McMurdo Station from a sprawling expeditionary camp to a small, compact city with all of the attendant support services of a modern community. Figure 3 shows some of these new facilities. In the foreground is the hut constructed by R.F. Scott in 1903; in the background are the new dormitories under construction in 1988.

This physical transformation from an expeditionary camp to a small, continuously occupied community has also resulted in a concurrent change in the attitude of the residents and the support and operational staffs involved, as evidenced during the senior author's visit to McMurdo Station in January 1988. There is, at present, improved continuity of experience since many of the support activities are managed under contract. Even more important is the long-term commitment, on the part of the entire population, to operate and maintain the community in a manner that will protect the health and safety of the residents and the general environment in accordance with all of the requirements of applicable treaties, codes, laws, regulations and agreements. In addition, there is a gradual and continuing effort to clean up the residuals from the earlier expeditionary years.

In the opinion of the authors of this report, this commitment on the part of the administrators, managers, and residents of the U.S. facilities in

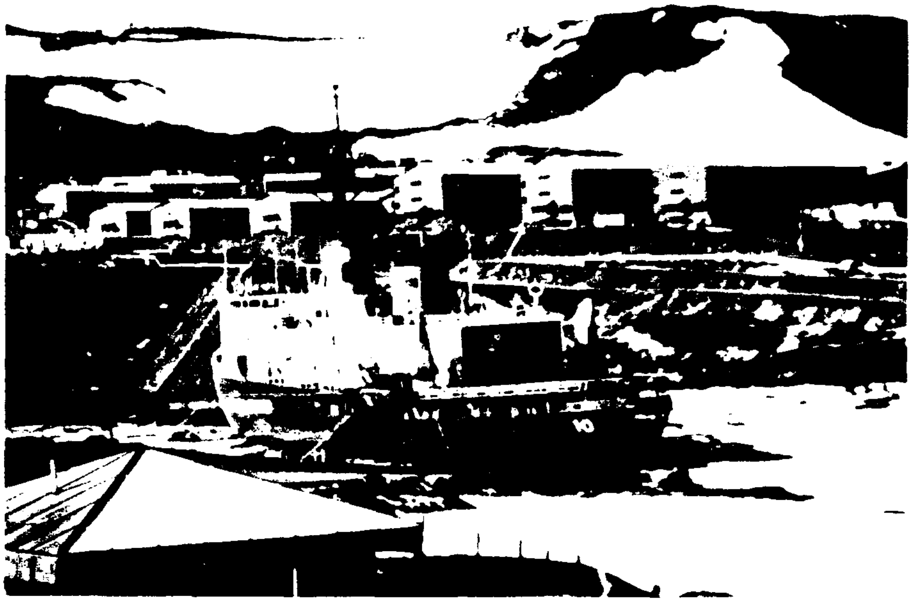

*Figure 3. New and original facilities at McMurdo Station.*

Antarctica is a critically important development. It is as important, if not more so, than the technical issues discussed in later sections of this report. It is this commitment that will ensure the successful and environmentally compatible presence of the United States in Antarctica.

The balance of this report addresses the technical aspects of waste management at McMurdo and the activities serviced by McMurdo. This includes a description and discussion of current practices, identification of opportunities for improvement and recommendations for the future. Since the site conditions and other geotechnical aspects strongly influence waste management practices, the text is organized by location, with sections covering McMurdo Station, Williams Field and Pole Station.

## MCMURDO STATION

McMurdo Station is located on the shore of McMurdo Sound, 2200 nautical miles from Christchurch, New Zealand, and 730 nautical miles from the South Pole. The mean annual temperature at this location is −0.4°F (low = −60°F, high = 41°F). The site is volcanic in origin, consisting primarily of basaltic rocks with cindery masses. Permafrost exists at a depth of 6 to 18 in. below the surface. Some of this rock contains interstitial ice in the joints within the upper 3 ft of depth. Thawing of this material would result in minor structural settlement. The station is occupied on a continuous basis, with a winter-over population of about 200 and ranging up to 1000 during the active summer season. The operation and maintenance of the station is provided, in part, by the US Navy and in part by a contractor (ITT Antarctic Services) to NSF. Table 1 summarizes population data for the major part of the 1987–88 season, and these are probably reasonable expectations for the future as well.

**Table 1. 1987–1988 Population data, McMurdo Station, Antarctica**

| *Month* | *Population* *Mean* | *High* | *Low* |
|---|---|---|---|
| 1987 "Winter-Over" | 189 | – | – |
| September | 327 | – | – |
| October | 758 | 937 | 368 |
| November | 923 | 964 | 895 |
| December | 878 | 895 | 841 |
| January | 884 | 928 | 857 |

Neither groundwater nor continuously available fresh surface water exist in the McMurdo area (a lake does exist to the northeast of the station and might be developed as an emergency source, or for fire protection in the summer months). Melted snow served as the water source during the early years of activity. However, the adjacent snowfields have receded during the past decades and it would be impractical, in any event, to harvest enough snow each day to serve the needs of the present population.

The present water supply system draws sea water from McMurdo Sound and utilizes flash evaporator distillation to produce the potable water supply for the station. This new distillation system includes two 40,000-gal./day (potable water production) units linked to the diesel-fired electrical power plant. Waste heat from the power plant is used to supply most of the heat for the distillation process. A stand-by distillation plant is also available for backup and emergencies. This distillation process has a production efficiency of about 33%, so that 1 gal. of potable water is produced from 3 gal. of seawater drawn into the system. The waste brine is returned to McMurdo Sound with the other wastewater from the station. The temperature of this waste brine is about 140°F. Heat-traced and insulated water pipe carries potable water to the occupied buildings at the station. Since high temperature distillation is used as the water treatment process it is not believed necessary to use chlorine or other disinfection agents.

Combining the water production data with the population values in Table 1 indicates that the average per capita water use is 56 gal./day. That is equivalent to the consumptive domestic water use (i.e., drinking, cooking, bathing, etc.) in any large city or suburban development in the United States where there are no restrictions on water use. At McMurdo, it can be assumed that consumptive use accounts for most of the water (there may be some use in construction and other incidentals during the summer). Water conservation devices (on sinks, toilets, etc.) are utilized in most of the buildings, and all residents are strongly encouraged to practice water conservation.

If a significant number of individuals do follow water conservation practices, there then must be excessive usage elsewhere to account for the 56-gal./day average value. The installation of water meters at selected locations and a water consumption study over an operational season would provide sufficient data to identify the major water users and to attempt the restoration of water conservation measures throughout the community. Any reduction in water use will extend the useful life of the new distillation plant.

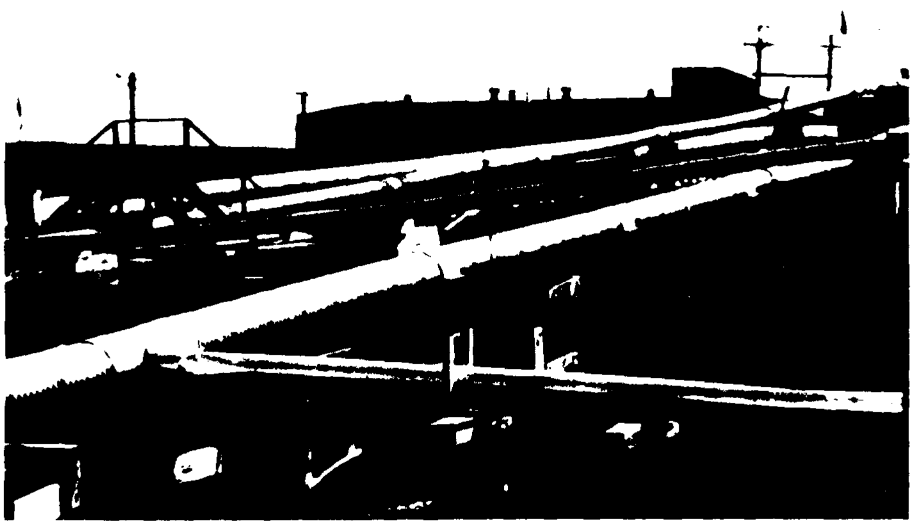

*Figure 4. Typical water and wastewater piping at McMurdo Station.*

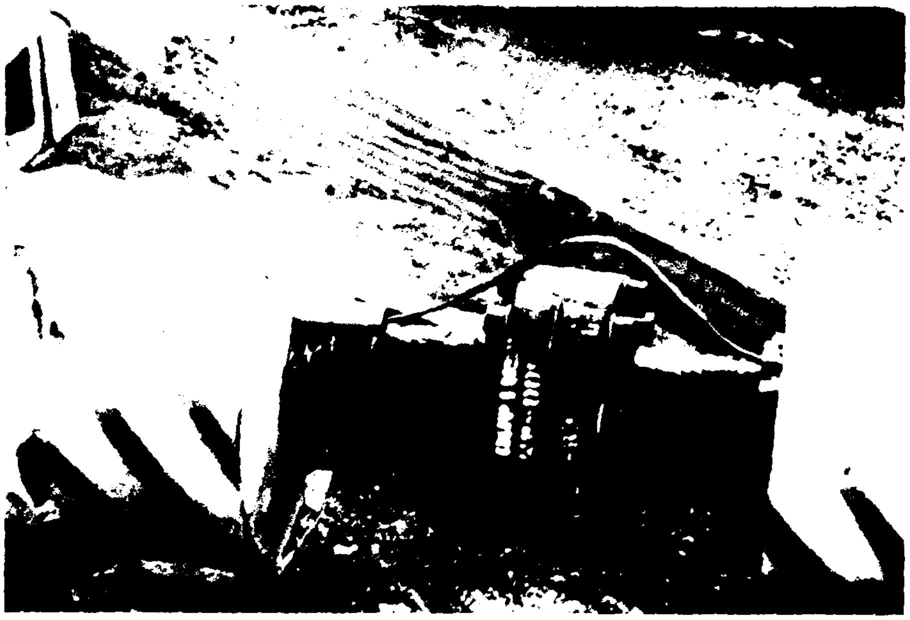

*Figure 5. Joint detail—heat-traced and insulated wastewater pipe.*

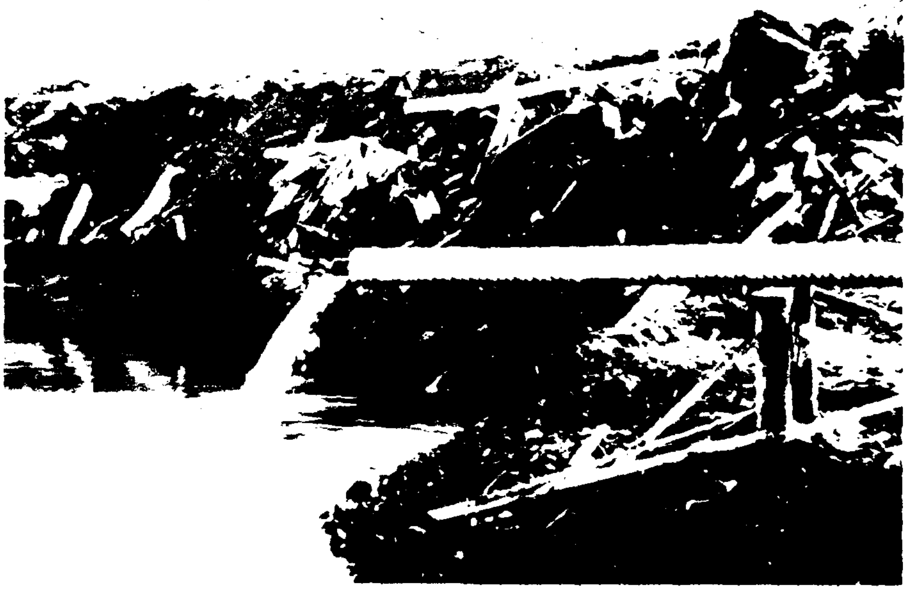

*Figure 6. McMurdo outfall for discharge of combined wastewater.*

**Wastewater management**

Wastewater is collected (from all buildings) and conveyed in insulated, heat-traced gravity pipes to the treatment facility where a macerator grinds the solids for particle size reduction. The wastewater is then combined with the warm waste distillation brine and discharged to McMurdo Sound. Figures 4 and 5 show the collection piping and Figure 6 shows the present outfall structure. The domestic wastewater also includes ground garbage from the dining facilities.

Table 2 presents estimates of the volume of wastewater discharged, based on the water usage and population data presented above. At the pres-

ent rate of water use, this wastewater is comparable, on a mass basis, to the discharge from an equal-sized, nonindustrial, rural community in the United States. The dilution provided by the warm brine reduces the concentration of the wastewater c nstituents, so the combined McMurdo wastewater is equivalent in quality to typical primary effluent at the point of discharge. This is comparable to the discharge practice at a number of coastal communities in the U.S. with access to the ocean (see Appendix A for a list). Based on the values in Table 2, the average combined wastewater discharge would be about 75,000 gal./day during an annual cycle, with one third of that being domestic wastewater. Applying a typical value for organic loading (0.22 lb/person per day including the ground garbage) the Biochemical Oxygen Demand ($BOD_5$) of the wastewater discharged to the Sound would be about 157 mg/L. The suspended solids (SS) should be roughly the same concentration as the BOD.

**Table 2. Estimated wastewater discharge at McMurdo Station.**

| | *Wastewater volume (gal./day)* | | |
|---|---|---|---|
| *Month* | *Domestic* | *Brine* | *Total* |
| Winter-Over | 11,200 | 22,400 | 33,600 |
| September | 18,312 | 36,624 | 54,936 |
| October | 42,448 | 84,8961 | 27,344 |
| November | 51,688 | 103,376 | 155,000 |
| December | 49,168 | 98,336 | 147,504 |
| January | 49,504 | 99,000 | 148,504 |
| February | 19,992 | 39,984 | 59,976 |

**Table 3. Combined wastewater characteristics, McMurdo Station.**

| *Parameter* | *Wastewater concentration (mg/L)* | *Drinking water requirement (mg/L)* |
|---|---|---|
| Ammonia | 11 | – |
| Arsenic | <0.001 | 0.05 |
| Barium | <0.003 | 1.0 |
| Cadmium | <0.001 | 0.01 |
| Chromium | <0.003 | 0.05 |
| Lead | 0.02 | 0.05 |
| Selenium | <0.001 | 0.01 |
| Silver | <0.02 | 0.05 |
| Mercury | <0.001 | 0.002 |

A study in 1986 measured other parameters directly at the McMurdo outfall (Raytheon Inc. 1986). These values, adjusted for the present brine dilution, are given in Table 3, and compared to USEPA requirements for drinking water.

A wastewater treatment system for McMurdo has been considered on several past occasions and is also under consideration for the coastal stations of other Treaty nations. The system concept most commonly proposed for these uses is some form of biological wastewater treatment plant to produce the equivalent of secondary effluent. Assuming that some degree of mixing and dispersion occurs in the ocean environment, there seems to be little rational basis for the use of any form of secondary treatment prior to discharge.

The principal function of secondary treatment is to reduce the concentration of the easily degraded organic compounds (BOD) in the wastewater to thereby reduce the oxygen demand in the receiving water. Secondary treatment was adopted in the United States and elsewhere in order to maintain desirable oxygen levels in inland freshwater streams. In most marine environments, with some circulation, mixing and dispersion, there is no need to remove the simple carbonaceous organics prior to discharge, especially at the concentrations experienced at McMurdo Station. At present loading rates, oxygen stress will not occur due to the untreated wastewater discharge, so there should be no adverse impact on the fish, mammals and other marine life. During the peak summer months, the mass organic loading will be the highest, but the assimilative capacity of the marine environment will also be at peak capacity. During this period it is estimated that the organic loading from McMurdo Station will be less than 10–15% of the BOD contribution from just the seal population of the Sound (5000 seals at 0.33 lb BOD/animal per day). The mixing and dispersion of the warm wastewater with the cold seawater should reduce wastewater concentrations to better than tertiary levels within a few hundred feet of the outfall.

Concern has also been expressed regarding the impact of metals and other wastewater constituents on marine life and the benthic community on the sea bottom adjacent to the station. The bottom slope is about 1:6 from the shore so that at a distance of about 150 ft offshore the depth is about 45 ft (20 ft deep at shoreline).

The sediments are composed of poorly sorted, compact silty sand with admixtures of gravel and

clay of volcanic origin. The benthic epifauna includes sponges, and various asteroid and molluscan predators, diatoms and other biogenic particles (Raytheon Inc. 1986). Bottom samples taken in 1986 showed no physical evidence of any sludge layers resulting from the wastewater discharge and this was prior to the addition of brine or the use of the macerator to reduce particle size.

If any changes occur, it is likely that fish, other animals and the benthic community in the vicinity of the outfall will be more productive due to the extra heat and nutrients added with the wastewater, instead of being damaged. A significant algal population was noted on the open water adjacent to the outfall during the visit in January 1988. This was a very local impact and would be reduced significantly if the outfall were submerged further offshore. The benthic community immediately adjacent to any outfall will be *different* than the community in a completely pristine environment, but that will be true regardless of the level of treatment that might be provided for the McMurdo wastewater. The only way to restore pristine conditions at the nearshore environment at McMurdo would be to close and remove the station.

Recent studies (Bascom 1982) show that metals in their usual inorganic forms are not concentrated through the marine food web. The animals detoxify themselves by sequestering the toxic metal with other substances found within their bodies. Bioaccumulation of trace metals and toxic organics alone cannot, therefore, be considered an indication of adverse effects of wastewater disposal unless the concentrations in seafood species approach maximum safe levels for human intake (Gunnerson 1988). At the concentrations listed in Table 3, bioaccumulation of any metals is considered to be very unlikely.

The discharge of mercury to the marine environment gained world-wide attention when a number of deaths in Japan were linked to the consumption of mercury-contaminated seafood. This incident was atypical. Very large quantities of methyl-mercury were released into Minamata Bay, which has poor circulation and limited dilution and dispersion. Nothing remotely similar should ever occur at McMurdo. The measurable effects of waste discharges are limited to the immediate area around an outfall. Far-field effects are extremely rare (Gunnerson 1988). The very low metal concentrations listed in Table 3 for the McMurdo wastewater should not cause adverse environmental impacts in the waters of McMurdo Sound.

The present discharge practice is in compliance with all requirements of the Treaty, as well as applicable laws, regulations and policy. In addition, it is identical to the systems used at comparable communities in the Arctic (Gov. NWT 1981, GTO 1984, Smith 1986). A survey of waste management practices in the Canadian Arctic and in Greenland (Gov. NWT 1981, GTO 1984) indicates that the larger coastal communities in Canada and all of the towns in Greenland utilize maceration and discharge of otherwise untreated wastewater to the sea. The Canadian communities include: Cape Dorset (pop. 700), Frobisher Bay (pop. 2419), Pangnirtung (pop. 900), Resolute Bay (pop. 1600) and Rankin Inlet (pop. 1000). The total population served in Greenland during 1980 was about 53,000 people. It is assumed that similar methods are also used at the arctic communities in Scandinavia and the USSR. There is nothing unique about the discharge practice at McMurdo, since it is in common use elsewhere and is considered more than adequate to protect the public health and the receiving environment at all of the locations cited in this report.

The Antarctic Conservation Act (1978) prohibits the discharge of pollutants within Antarctica by US citizens. Pollutants are defined as a substance "to create hazards to human health, to harm living resources or marine life, to damage amenities, or to interfere with other legitimate uses of Antarctica." The present wastewater discharge practice creates none of these impacts and therefore is acceptable under the law. The criticism of U.S. practices found in the popular press and other literature (Barnes et al. 1987, Mitchell 1988, Dumanoski 1988) is based more on unfounded speculation than established fact with respect to environmental impacts. The corrective actions often recommended by these critics would provide little to no environmental benefit.

As a result of the discussion above, there seems to be no justification for using more sophisticated wastewater treatment systems or to changing the basic discharge method at McMurdo Station. However, some improvements in the present system are possible. At present, there is an intermittently used outfall at the VXE-6 hangar area, and a temporary outfall serving some of the newly constructed buildings, which discharges to Winter Quarters Bay. As soon as related construction is complete, these outfalls will be closed and all

wastewater conveyed to the central macerator/ discharge point.

The present outfall is about 500 yd from the seawater intake, which is the source for the station water supply. Even though an earlier study (Raytheon 1986) indicated minimal risk, and the distillation process itself provides protection, it would be prudent to examine the waters between the outfall and the intake to determine if bacterial transport toward the intake is occurring. Samples could be taken on a grid pattern between the two points and analyzed for at least total and fecal coliforms. The study period should include a brief period in September or October when the ice is still competent and again in mid- to late January during a warmer part of the year. Sampling of the near surface waters should be adequate since the present discharge configuration provides the worst-case condition. As shown on Figure 6, the outfall is elevated and discharges to the ocean surface. This may result in minimal mixing and dispersion since the warm water will initially tend to *float* on top of the colder, more dense sea water. If surface currents exist, this may provide an opportunity for movement of bacteria toward the water intake, through tidal cracks and just beneath the ice.

For the long term, strong consideration should be given to constructing a submerged outfall, extending at least 100 ft into the waters of the Sound, with a single outlet at the end. This would maximize the opportunity for mixing and dispersion since the water depth at the point of discharge would be at least 40 ft. Such an outfall must be buried, or otherwise protected, at the tidal transition zone to prevent destruction by the moving sea ice. Once that zone is passed, the pipe can be laid directly on the bottom and construction would be relatively simple by cutting a slot in the ice during the early part of the summer season. Construction at the transition and especially through the fill area adjacent to the present outfall would be much more difficult. In order to avoid construction difficulties at the fill area, it might be possible to locate the new outfall at a less disturbed part of the shoreline.

Once a submerged outfall is in place, there will be less need for the dilution now provided by the waste brine, and consideration might be given to the beneficial reuse of this warm water elsewhere on the station. It should be possible to recover (with heat exchangers) a significant part of the heat in this brine and this in turn might be used to heat one or more of the adjacent buildings.

Another possibility might be to use the hot water during the summer months to assist with snow disposal. The major streets at the station are plowed during the winter season, and this is required frequently since drifting can be severe. Since the plowed snow may contain trash and other debris, it is not disposed of on the sea ice but is stockpiled on the land and (it is hoped) melts during the following summer. It might be possible to fence (to contain the trash and debris) a suitable area and then use the warm brine with spray guns or sprinklers to accelerate the snow melting during the summer.

The warm brine might also serve as an emergency water source for fire protection. This would require a large tank on the uphill side of the station. The continuous input of warm water (and gravity return to the Sound) would keep the tank and the related piping from freezing and provide a large volume of water that could be put into the piping system for emergency fire fighting.

In this context, it might be useful to conduct a study that would evaluate the potential for water conservation and water reuse at McMurdo and the major stations supported from McMurdo. Although much of the energy used to produce water at McMurdo comes from waste heat, any significant water conservation at any of the stations should yield a concurrent savings in energy and therefore fuel.

A final point in this wastewater management discussion concerns toxic and hazardous liquids. The current practice of neutralization prior to discharge or retrograde should be continued. For the same reason, chlorine should not be used in an attempt to disinfect the wastewater prior to discharge. Chlorine will react with the organic materials in seawater to produce chlorinated organic compounds such as chloroform, a known carcinogen and mutagen. In addition, the USAP should strengthen its awareness program so that introduction of toxic and hazardous substances will be avoided whenever possible and, if necessary for research or other purposes, that these materials not be discharged in the domestic wastewater at McMurdo.

**Solid waste management**

Solid wastes at McMurdo Station can be divided into three categories:

- Combustible wastes (trash, construction debris)
- Noncombustible wastes (scrap metal, construction debris, unusable equipment and vehicles)
- Nondegradable or hazardous wastes (tires, batteries, spent lubricants, antifreeze).

In accordance with the Treaty and long-standing policy, materials in the final category are collected and removed from Antarctica. During the 1986–87 season about 1900 tons of waste lubricants, drums, batteries, tires, vehicles, vehicle parts, scrap metal and scientific equipment no longer needed was carried out on the ship MV *Greenwave*.

In earlier years, materials in the first two categories were placed on the nearby sea ice along with snow removed from the streets, in the hope that breakup would carry the materials away for disposal at sea. This practice has been gradually reduced and was terminated completely in 1987.

In the early 1970s an incinerator was installed in an attempt to deal with the combustible wastes produced at McMurdo. By 1972, the system was considered a failure (a similar unit installed at the Naval Research Laboratory in Barrow, Alaska, failed at the same time and for the same reasons) and was abandoned. The incinerator units were removed and the building at McMurdo is currently used as a workshop. It is instructive to examine the reasons for this failure prior to future consideration of a new incinerator for solid waste management at McMurdo Station.

The entrance door to the incinerator building was only 4 in. wider (on each side) than the forklift Dumpster and overhead clearance did not allow tipping the Dumpster container to off-load the trash. Any trash carried to the facility on trucks had to be manually offloaded in front of the building. The charging doors of the incinerators were refractory-lined guillotine types, but were too small (2 $ft^2$) for entry of much of the waste materials (pallets, packing boxes, etc.). It was necessary to feed the incinerator by hand shoveling and to remove the ash by the same method. The capacity of the units was about 15 $ft^3$ of small-sized dry trash per hour. Since the combustion of wet garbage was also attempted, the fuel requirements were very high. It was estimated that 95 gal. of oil (DFA) were required to burn 1 $ft^3$ of wet garbage. It was further estimated that during the winter months when the population was the lowest and trash production and construction wastes at a minimum level, it would require two men to operate the facility on an eight-hour, seven-day-per-week shift. It was observed at the time that "... the system is unsatisfactory due to inappropriate design and capacity, and only serves as a costly gesture to appease environmental and newspaper ecologists."

Some of the conditions that led to this early failure are no longer a factor since the food wastes and garbage are ground, macerated and discharged to the sea with the wastewater. However, based on the senior author's investigation in January 1988, the characteristics of the other combustible wastes would still complicate utilization of an incinerator system. It seems likely that the original design was based on the assumption that the waste would be mostly composed of typical small-sized domestic materials (paper products, etc.). Those components are present in the McMurdo wastes but there is also a very significant fraction of large-sized objects such as pallets, large packing boxes, scrap lumber and timbers, etc. An incinerator system to manage these wastes would have to be relatively large and have complex shredding or grinding equipment to reduce the particle size of the wastes. In addition, since the population and activities vary so much in the winter and summer seasons it might be necessary to bale and store the wastes for incineration during the summer season.

Some of the Treaty nations do have incinerator units at their stations. A notable example is New Zealand's Scott Base which is close to McMurdo Station. Scott Base is often cited in the popular literature as a station where environmental protection is a paramount concern. This implies that environmental matters are a lesser concern at McMurdo Station since open burning is still practiced. However, the incinerator at Scott Base suffers from some of the same limitations as the unit installed at McMurdo in the early 70s. It is a hand-fed, batch-type unit with a relatively small entry door. Any objects of inconveniently large size are trucked over to the McMurdo site for open burning (see Fig. 9). In effect, the McMurdo operation is subsidizing the high environmental reputation of Scott Base.

At the present time, both combustible wastes and scrap metal are brought to the Fortress Rock disposal site. Behind the Fortress Rock is a large depression that is partly a natural cirque and partly an old quarry and borrow pit. This site has


*Figure 7. Typical McMurdo Dumpster and plastic bag disposal.*

been used for solid waste management since 1980 (Waldrip 1984). Scrap metal is brought to the site and segregated for future disposal. During 1987–88 this involved cutting up the large pieces so they could be packed into appropriate containers for retrograde to the United States. It was reported that about 75% of the accumulated material was placed on the ship at the end of the 1987–88 season.

Trash and other combustible wastes are brought to the site by the assigned fork-lift Dumpster, or other fork lifts or trucks. In addition, there is a truck with a two- or three-man crew ("the rat patrol") that drives around the station picking up objects too large for disposal in the Dumpsters. Not counting the intermittent activity by the other vehicles, there are at least five contractor personnel involved on a daily basis with management of the solid wastes at McMurdo.

A preliminary solid waste characterization study at McMurdo was conducted in January 1988 during the senior author's visit to Antarctica. This attempted to define the composition, source, volume and weight of the combustible wastes and an estimate of the volume, composition and weight of the accumulated scrap metal.

In January 1988 there were 44 Dumpsters located at various sites around McMurdo Station; there were 28 in 1979, and 31 in 1984 (Ward 1979, Waldrip 1984). Four of the existing Dumpsters are used for scrap metals only, leaving 40 for combustible wastes. These Dumpsters were fabricated at McMurdo from sheet steel and have special connections for pickup and dumping using a fork lift.

The domestic and kitchen wastes (e.g., paper products, cans, etc.) are typically contained in a tied plastic bag and placed in the Dumpster for disposal (see Fig. 7). The Dumpsters are picked up by the fork lift and carried to the Fortress Rock site. The round trip from "town" to the site ranges from 15 to 20 minutes depending on the location. The procedure is not very efficient since the loosely packed plastic bags can rapidly fill up the Dumpster. As part of the characterization study, the contents of selected Dumpsters were weighed with a hanging spring balance. The typical weight for the dormitories and the clubs ranged from 100 to 150 lb of solid waste in a Dumpster. The maximum value observed was 253 lb in a Dumpster from the galley. The Dumpster container itself weighs at least an order of magnitude more than the loose contents, and this loose packing in turn requires more frequent trips (and more fuel and more labor). It is not practical to put trash compactors in every building but it could be very

*Figure 8. Fork-lift Dumpster at Fortress Rock landfill site.*

*Figure 9. Unloading a truck at the Fortress Rock landfill site.*

beneficial to locate some units at the major trash sources. Based on the survey in early January, these locations were: the galley, the Acey Deucy Club, the Navy administration building, and "Hill Cargo." All of these locations required at least one trip a day during the 12-day study period (the galley required 69 trips during this period). These four locations accounted for 45% of the trash with the remainder coming from the other 36 Dumpsters. The installation and use of a heavy-duty, commercial-grade trash compactor at each of these four locations might reduce the Dumpster collection activity by 25 to 30%.

Most of the food waste and garbage is macerated and disposed of with the wastewater and this practice should continue. Disposal of the garbage (although combustible) at the Fortress Rock site will attract Skua gulls, interfering with their normal food habits and the bird research conducted in adjacent rookeries. Some minimal food waste does reach the site since the dining hall occasionally uses paper plates, a few meals are taken from the galley to people on duty in other buildings, and snacks are consumed in the dormitories and clubs. Segregation of these incidental food wastes is not practical. To prevent problems, all Dumpsters should be covered with hinged, heavy-duty wire mesh to prevent bird access, and the accumulated material at the landfill site should be burned on a regular schedule.

Figure 8 illustrates the fork-lift Dumpster at the landfill site, and Figure 9 shows offloading from a truck (a contribution from Scott Base).

The composition of the combustible wastes delivered to Fortress Rock is similar in many respects to any small community in the United States, but very different in others. The quantity of domestic wastes is about the same (paper products, cans, etc.), but there are no yard wastes (grass and tree trimmings, leaves, etc.). The missing yard wastes are replaced by a high percentage of packing materials, and construction wastes (scrap lumber, timbers, etc.). Almost everything that is shipped to McMurdo is packed in heavy-duty cardboard or wood containers, which are also usually banded to a wooden pallet. All of these materials end up at the landfill. Figures 10 and 11 show a 12-day accumulation of combustible trash at the landfill site.

The estimated volume of the accumulated trash shown in Figures 10 and 11, using a hand level and tape, was 55,236 $ft^3$. The average pro-

*Figure 10. A 12-day accumulation of trash at the McMurdo landfill.*

*Figure 11. A side view of the accumulation shown in Figure 10.*

duction rate during the 12-day period would be 4603 $ft^3$/day. The McMurdo population during the period was 977, so the average per capita production was 4.7 $ft^3$/day. About 80% was delivered by the fork-lift Dumpster, with the remainder from other sources (see Appendix A for details).

During the 12-day observation period there were 230 Dumpster deliveries; applying the average content weight (197 lb/Dumpster) yields a per capita rate of 3.9 lb/day. It is estimated that the domestic contribution from the dormitories and other living spaces is about 3 lb/person per day. The galley, shops, offices and construction activities are estimated to contribute about 1800 lb/day. This yields a total of 4.8 lb/day per capita for all combustible wastes produced at the station. This agrees closely with the estimate of 5 lb/day per capita made by Holmes & Narver (1979), and is also comparable to the per capita rate for a typical community in the U.S.

Since the Dumpsters account for 3.9 lb/day per capita the other sources must deliver 0.9 lb/day per capita. At a summer design population of 1000 the daily load would be 2.4 tons/day. In the winter months, with 200 people and reduced construction and shop activity, the production is estimated to be 0.4 tons/day. The resulting annual total for combustible wastes at McMurdo is therefore at least 500 tons /yr or about 1,000,000 $ft^3$ of loose to semi-compacted material. This would rapidly overwhelm the capacity of the Fortress Rock site unless a very significant volume reduction technique is utilized. Open burning is the method currently used to achieve the necessary volume reduction. This practice is allowed by the Treaty and all applicable regulations and policy.

Figure 12 shows the burning operation in progress. This is done about every two weeks, preferably on a Saturday. About 5000 gal. of waste fuel oil from tank trucks is spread around the base of the pile and then ignited by a flare pistol. The fuel used is the residual from the storage tanks and from cleaning the wing tanks of the C130 aircraft when these are used to carry diesel fuel to Pole Station. This fuel has no other use at the station and if not burned would have to be removed from Antarctica in drums.

During the first few minutes following ignition there is some black smoke probably due to incomplete combustion of the fuel oil. The fire then burns very hot with minimal smoke and loss of airborne particulate matter. The fire is so hot that aluminum cans and other soft metals are consumed. Within a few hours there is virtually no smoke plume visible from anywhere in town.

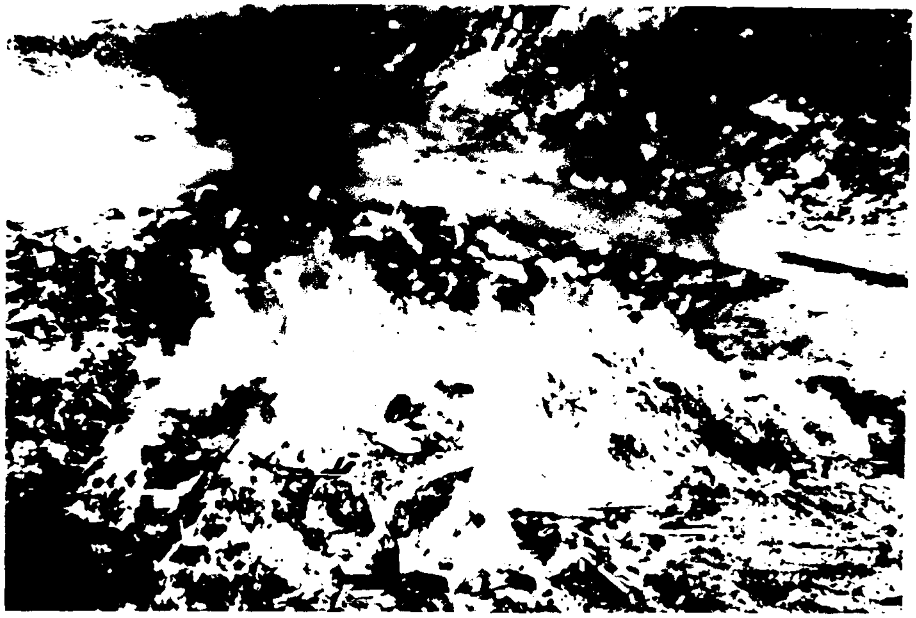

*Figure 12. Trash burning at the Fortress Rock landfill.*

Combustion is essentially complete within two days and operation of the Dumpsters typically resumes at that time.

The environmental impact of these short burning periods is believed to be minimal. The exhaust from diesel engines, heaters and vehicles in continuous operation at McMurdo, along with the dust from the roads, probably has a greater atmospheric impact than the infrequent burning operations. Open burning of solid waste has been banned for some time in the U.S. but the two situations are not comparable. Open burning at a typical dump in the U.S. occurred continuously at a smoldering rate and produced a great deal of smoke, particulate matter and objectionable odors from the garbage. The exclusion of garbage, and the use of waste oil at McMurdo, produces a hot, quick fire that consumes all combustible materials very rapidly. It also uses the waste fuel oil in a beneficial manner with minimal impact on the environment.

It would be possible for McMurdo to install incinerators of the type used at Scott Base that are designed for the small-sized domestic wastes. This, however, would only solve part of the problem since the large objects and construction wastes from both McMurdo and Scott Base would still require disposal. An incinerator system designed for all of the combustible wastes would, as described previously, probably require shredders, balers, a building for the incinerator and a large storage shed for the baled waste. The final alternative would be to shred, bale and then retrograde all of the combustible wastes each year, along with the thousands of gallons of waste fuel oil previously burned. This would also require a very large shed for storage of the annual production of baled wastes and possibly another ship for removal. The waste fuel oil would not be suitable for direct use in any incinerator system since the contained particulate matter would clog the burner nozzles. A filtration system would be required to prepare the fuel for use.

A concept intermediate between open burning and a full scale incinerator is the open-pit incinerator. Developed in Canada, it has been suggested for use at remote villages in the Canadian Arctic (O'Connell and Zaidi 1979). The basic configuration includes a concrete- or metal-lined pit, or box, with an internal lining of refractory brick. A forced-air blower provides air to manifolds and nozzles around the bottom perimeter of the pit

and around the top. The upper nozzles provide "over-fire" air and serve as a crude afterburner, partially suppressing loss of particulate matter and partially combusted gases. A small pilot unit, 5 x 7 x 5 ft deep, was tested in northern Canada for the domestic solid wastes and garbage from an Indian village, and was rated at 500 lb/hr capacity. A significant scale-up would be required to use the concept at McMurdo and it has not been successfully tested at that level. It would be necessary, prior to consideration of any incinerator system, to conduct a thorough waste characterization study to quantify the thermal characteristics and water content.

None of the alternatives discussed above offer environmental or other benefits commensurate with the cost to implement and then operate any of them. On a world scale it makes little sense to transport baled waste thousands of miles for disposal in a landfill or by incineration when it can be managed directly and effectively at McMurdo Station.

Recycle and the use of alternate materials have been suggested as possible techniques to reduce the volume and the impact of the materials that are burned. Recycle typically commences from an environmental ethic but is seldom practiced anywhere in the world unless there is an economic benefit produced by the practice. Because of the high labor costs and long distances involved, there can be no economic benefit realized from recycle of metals and other common disposable materials.

Although aluminum beverage cans are essentially completely consumed during the burning operation, steel food cans are not. For the long term, consideration might be given to the segregation of all food and beverage cans, which would then be crushed and baled and disposed of with the other scrap metal from the station. This might provide some additional capacity for the landfill. Consideration might also be given to eliminating the use of polystyrene foam and other plastics wherever possible. The use of paper plates and cups instead of plastic is already common and other possibilities may exist.

Wooden pallets are a significant part of the combustible waste taken to the Fortress Rock site. A major portion of all items shipped to McMurdo are packed in cardboard containers and then banded to wooden pallets. These inexpensive pallets are only intended for a single use and recycle and reuse is not practical or economical. Even if heavy-duty plastic or aluminum pallets were used, recycle to the original source would be difficult and expensive when the locations of the many diverse vendors and suppliers are considered. It might be possible to repackage the materials onto plastic or aluminum pallets at the major shipping ports (California, New Zealand), and then recycle these pallets from McMurdo to these points. This would still be expensive and provide minimal environmental benefit since the wooden pallets can be burned efficiently at McMurdo.

In summary, the current practice of open burning at Fortress Rock is believed to be environmentally compatible and the most effective alternative available for management of the combustible solid wastes at McMurdo Station. The site should have a useful capacity at least through the year 2000 if properly managed (Waldrip 1984). At present, and for the near future, there are intensive construction and cleanup activities in progress. When these efforts are completed, it is reasonable to expect that the volume of waste produced annually will be less and the site may have an operational capability beyond the year 2000.

There are, however, several things that can be done at the site to further reduce environmental impacts and to make the operation more effective. Two of these are already being implemented: the runoff water from adjacent snow fields should not run through the landfill area but should be diverted with appropriate ditches as described by Waldrip (1984), and fencing should be installed to contain the paper, etc., blown from the trash pile during windy periods. Most of the fence posts were in place at the time of the senior author's visit in January 1988. This work should be completed as soon as possible and the fence possibly extended 50 to 100 ft further up the Arrival Heights Road (beyond the January 1988 position) to ensure containment of all blowing material.

The effective operation of the site requires the use of a heavy vehicle (D6 or D8 tractor or similar) to push the material down the face of the landfill for more effective burning, and then to compact the ash when burning is complete. This was not observed during the January 1988 visit but is essential to take maximum advantage of the available space at the Fortress Rock site. At the end of the summer season, the same vehicle can push a soil layer over the compacted material.

*Figure 13. Scrap metal accumulation, McMurdo Station.*

**Management of scrap metal**

Sources of scrap metal at McMurdo are daily operations, construction activities and cleanup of residues from previous years. The latter two are the major sources of the scrap metal collected at the Fortress Rock site. Also included is scrap metal from New Zealand's Scott Base, so McMurdo is again responsible for preserving the environmental character of the neighboring base. Figure 13 shows the scrap metal accumulated at the Fortress Rock site as of January 1988 and, in essence, represents a one-year accumulation. The volume of this material, as measured with a hand level and tape, was about 21,000 $ft^3$. Depending on assumptions made about the void space in the pile and the type of metals contained (mostly steel and aluminum) the total weight might range from 100 to 200 tons. It was the intention to remove all of this accumulated metal by the end of the 1987–88 season and, as reported in a previous section of this report, about 75% was loaded on the ship for retrograde.

This retrograde operation is a very labor-intensive activity. The metal objects must be cut up into manageable pieces, packed into suitable containers, moved to Winter Quarters Bay and loaded on the ship. This approach is inefficient and costly, and does not serve to protect the environment in a significant way.

A more effective approach would be to plan for the managed disposal of this scrap metal in deep water. This does *not* mean the revival of the old approach of the random placement of wastes on the nearshore ice and then waiting for the ice to breakup and move. Disposal of these metals in deep water (>100 fathoms) is compatible with the Treaty and all related requirements and guidelines. Water of that depth is available within a mile of McMurdo Station. An opening could be cut in the ice with a ditching machine, the scrap metal trucked to the site and dropped in. Alternately, explosive charges of appropriate size and in a proper pattern could be set, the scrap metal placed, and then the ice broken up by blasting and the metal allowed to sink. Either approach could be undertaken and completed early in the summer season when the ice is able to support heavy vehicles. This would be well before the return of seals, penguins and whales to McMurdo Sound so there would be no interference with marine life. The only impact would be limited to the sea bottom in the immediate vicinity of the disposal site. The presence of these metals (essentially all iron and aluminum) should not result in contamination of the water column above.

In summary, although retrograde of the scrap steel and aluminum is technically feasible, the environmental benefits realized are marginal to

nonexistent. It is suggested that strong consideration be given to the managed deep-water disposal of these materials. Since a very large portion of these scrap metals comes from construction, demolition of old buildings and cleanup, it is likely that the amount to be managed each year will diminish significantly when these activities are completed in the near future.

## WILLIAMS FIELD

The location of Williams Field with respect to McMurdo Station is shown on Figure 2. This snow runway airfield is the major transit point for flights to and from New Zealand and for support of stations in the interior of Antarctica. The snow layers overlie the glacial ice of the Ross Ice Shelf. The snow runway and the support facilities are periodically relocated due to the continuous lateral movement of the ice shelf. Access to the station from McMurdo is via a road over the annual sea ice during the early part of the season, and then an overland road connecting directly to the Ice Shelf after the sea ice begins to degrade. A runway on the annual ice allows the use of wheeled aircraft during the early part of the season (October to mid-December). The temporary facilities at this ice runway are moved each year and are not included in this report.

**Table 4. 1987–1988 Population data, Williams Field, Antarctica.**

| | *Population* | | |
|---|---|---|---|
| *Month* | *Mean* | *High* | *Low* |
| 1987 "Winter-Over" | 0 | 0 | 0 |
| September | 17 | – | – |
| October | 69 | 129 | 16 |
| November | 126 | 129 | 115 |
| December | 135 | 141 | 128 |
| January | 142 | 144 | 140 |

Williams Field is a self-contained facility that is continuously occupied during the operating season, with its own power supply and utility network. Typical structures at Williams Field are shown in Figure 14. The facility is operated by contract personnel (ITT Antarctic Services) for NSF. The buildings and other facilities are secured and closed down for the winter and then reopened at the start of the next season. Population data for the 1987–88 season through January are given in Table 4. The water source for Williams Field is melted snow. A small tractor collects snow from a protected site upwind of the station and, as

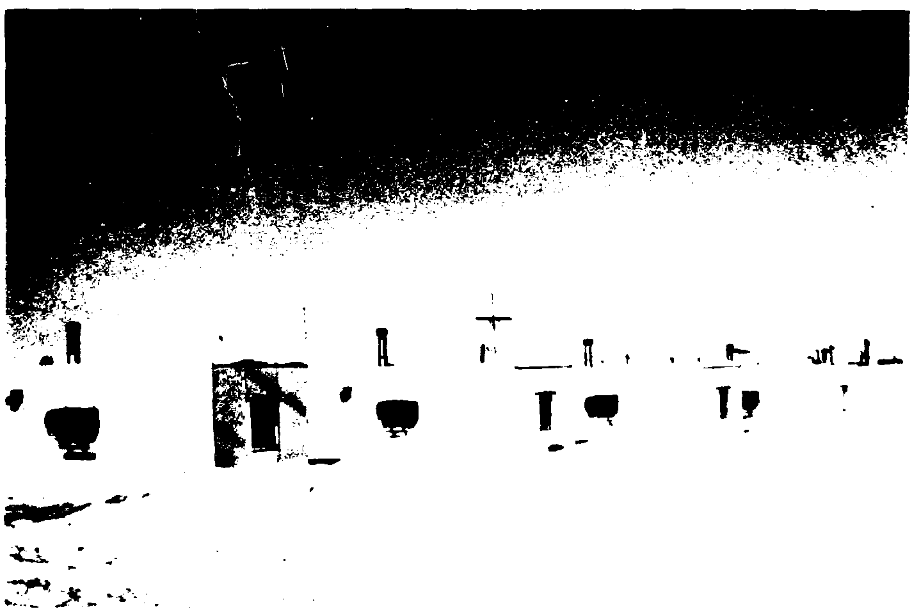

*Figure 14. Typical buildings at Williams Field, Antarctica.*

*Figure 15. Snow melter operation, Williams Field, Antarctica.*

shown in Figure 15, dumps this into the hopper of a snowmelter tank. The melt water is filtered and disinfected prior to distribution. Based on production estimates in January, the per capita water use at this facility is about 36 gal./day. In 1970, the water use was estimated at about 20 gal./day per capita (Valentine 1972).

**Wastewater management**

Wastewater discharge to either McMurdo Sound or to the sea water beneath the Ross Ice Shelf is not practical, so the snow pack overlying the glacial ice is used instead. This is a proven technique, which is safe, reliable, and environmentally compatible (Reed and Tobiasson 1966, Parker et al. 1978, Reed et al. 1985).

The density of a deep snow pack typically is less than 20 lb/ft$^3$ for loose newly fallen snow on the surface, and approaches that of ice (55 lb/ft$^3$) at depth. On the ice cap of southern Greenland this transition to ice occurs at a depth of about 130 ft; at the South Pole the interface point is about 360 ft below the surface. At Williams Field, the transition point is likely to occur at the interface between the snow pack and the glacial ice of the Ross Ice Shelf (at least 40 ft deep). The snow between the surface and this transition point is permeable and liquids can percolate. The vertical penetration of the liquid is dependent on its volume and temperature, and on the temperature of the surrounding snow. The conditions at stations in southern Greenland (mean annual temperature 0°F) allowed wastewater penetration to the ice interface. At the South Pole where the mean annual temperature is –56°F, it is likely that wastewater will freeze long before it reaches the 360-ft transition point. At Williams Field, it is likely that the 5000 gal./day discharge during the peak operating season will reach, but not penetrate, the snow/glacial ice interface.

Figure 16 shows a lateral cross section of one of these disposal operations, as measured at a station on the ice cap of southern Greenland (Reed and Tobiasson 1966). The warm wastewater will penetrate and melt vertically until it either reaches an ice barrier or freezes. Subsequent wastewater flow will melt a cavity containing a pool of unfrozen liquid. The hydrostatic head from this pool causes lateral percolation into the permeable snow, until the liquid freezes. This is the outer zone shown in Figure 16. The amount of lateral penetration is also a function of snow temperature, the head available and the temperature of the liquid. The volume involved on Figure

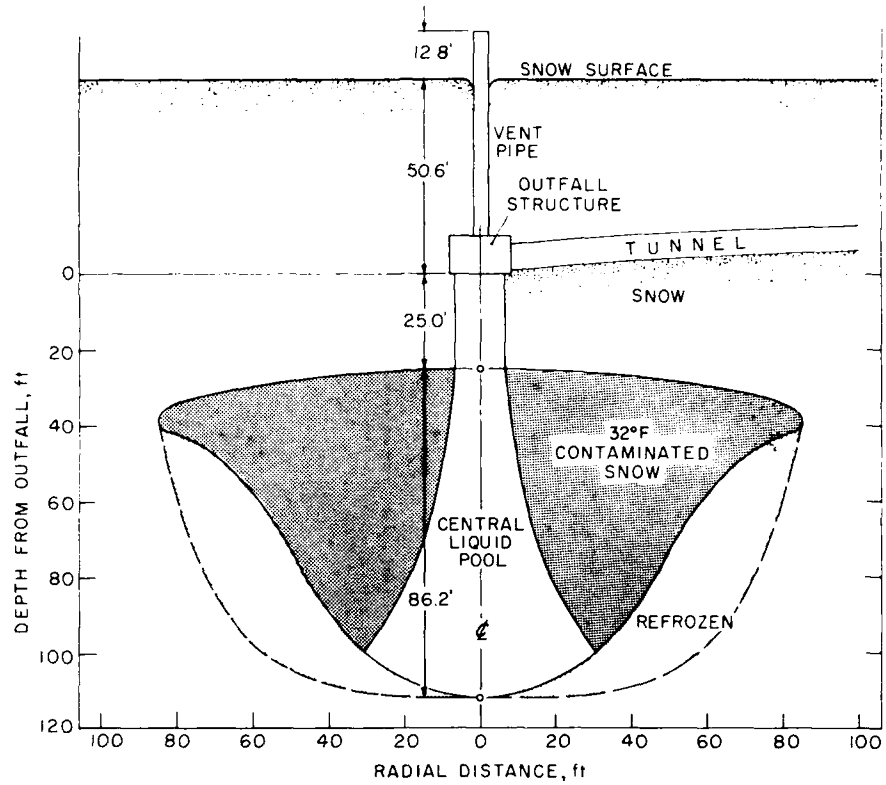


*Figure 16. Wastewater disposal on the Greenland ice cap.*

16 was about 200 ft in diameter resulting from an average flow of less than 2000 gal./day.

Eventually, sufficient heat is lost from the liquid at the lower boundary and it freezes. In effect, this impermeable barrier moves upward with time and, as a consequence, so does the liquid surface. Over a long period of time, the liquid surface will move up close to the outfall pipe. At this point the system is "full" and the outfall must be moved to a new location. At the station studied in Greenland this is required every three to five years. Another concern is the gradual heat losses from the liquid; this heat loss will warm the adjacent snow and may induce more rapid settlement of adjacent structures.

Assuming a 30-ft usable snow depth at Williams Field, with porosity varying from zero at the ice interface to 50% near the surface, there would be sufficient void space in the snowpack, within a 300-ft diameter, to accommodate at least 3 million gallons of wastewater. This is more than sufficient for five years of use at the water consumption rate cited above.

There are no health or environmental concerns with this practice since the wastewater is permanently contained in the snow pack and gradually will become part of the glacial ice as additional new snow accumulates on the surface and consolidates the adjacent snowpack. This form of wastewater disposal was described in the first environmental impact statement ever prepared for a U.S. project in Antarctica (Parker et al. 1978) and was approved for use at the Ross Ice Shelf drilling project.

Since the Ross Ice Shelf moves laterally, the contained, completely frozen wastes will eventually calve as the lower portion of an iceberg, float to sea and distribute gradually into the open ocean. The concentration of frozen wastewater constituents would be quite low since they would represent less than 25% of the volume melting (if the entire iceberg were contaminated). As a result, this eventual melting and dispersion would have no greater impact on the open ocean than discharge of effluent from secondary treatment or better. At the Ross Ice Shelf drilling project it

was estimated that 1000 years would be required for the contained wastes to just move to the ice front (Parker et al. 1978). A shorter time would probably be the case at Williams Field.

Due to the wastewater volume and temperature at Williams Field, it is possible that the liquid might spread to a diameter of 300 ft or more beneath the outfall before it begins to rise. Since the useful life of an outfall point is estimated above to be about five years (for a 300-ft-diameter zone), and since the entire station is moved periodically, it may not be necessary to establish a new outfall at shorter intervals. This issue is discussed in greater detail in the section on Pole Station, but data on the lateral extent and rate of rise of the system at Williams Field would be very useful for future planning.

In summary, it can be concluded that the present wastewater disposal method in use at Williams Field is the optimum choice for the site conditions and should be continued.

### Solid waste management

Scrap metal, unusable equipment, obsolete vehicles, tires, batteries, spent lubricants, etc., are taken from Williams Field to McMurdo Station for disposal as described in the previous section. Garbage and combustible trash are disposed of via landfill in a trench excavated in the snow. Burning is occasionally utilized for volume reduction. The ultimate fate of these materials is the same as described previously for the Williams Field wastewater. A solid waste characterization study was not attempted at Williams Field due to project time limitations. Since construction and cleanup activities are minimal at this location as compared to McMurdo, the solid wastes at Williams field should be essentially domestic in character along with the related packing materials. Since garbage is included in the Williams Field solid wastes, the per capita production rate is probably close to the 5 lb/day discussed previously.

## POLE STATION

The location of Pole Station with respect to McMurdo and Williams Field is shown on Figure 2. Pole Station, at an elevation of 9200 ft, is supported and surrounded by the snow and ice of the Antarctic Ice Cap. This snow provides the foundation support for the station buildings, is the water source for the station residents, and is the receptacle for liquid and solid wastes. The mean annual temperature at this location is –59°F. The main buildings at the station are enclosed in a 164-ft-diameter (52 ft high at the center) geodesic dome (see Fig. 17) which prevents burial of these structures by drifting snow. All fuel, food, equipment, personnel and other supplies are carried from Williams Field to Pole Station on ski-equipped aircraft during the summer season. Pole Station is continuously occupied on a year-round basis. Table 5 presents population data for the 1987–88 season.

**Table 5. 1987–1988 Population data, Pole Station, Antarctica.**

| Month | Population Mean | Population High | Population Low |
|---|---|---|---|
| 1987 "Winter-Over" | 17 | – | – |
| September | 17 | – | – |
| October | 17 | – | – |
| November | 61 | 68 | 44 |
| December | 66 | 75 | 64 |
| January | 71 | 77 | 68 |

The water source for Pole Station is melted snow. Equipment and procedures are similar to those described previously for Williams Field (see Fig. 15). Based on production data for the 1988 summer season, the per capita water use at this facility is about 21 gal./day. In 1970, the water use was estimated at about 22 gal./day per capita (Valentine 1972). This water usage is less than 40% of the present rate observed at McMurdo and reflects the vigorous and continuing water conservation measures used at Pole Station. Water conservation at this site is absolutely essential due to the high cost of fuel, and the relative difficulty of operating and maintaining the snow-harvesting equipment under extreme low temperature conditions.

### Wastewater management

Wastewater is collected, and conveyed in heat traced pipe to the outfall discharge point. When the station was constructed, this outfall point was at the end of a metal-lined tunnel (see Fig. 18). At present, wastewater is collected in a small tank in the tunnel, pumped vertically to the snow surface and carried laterally in heat-traced and

*Figure 17. Exterior view, South Pole Station, Antarctica (1979).*

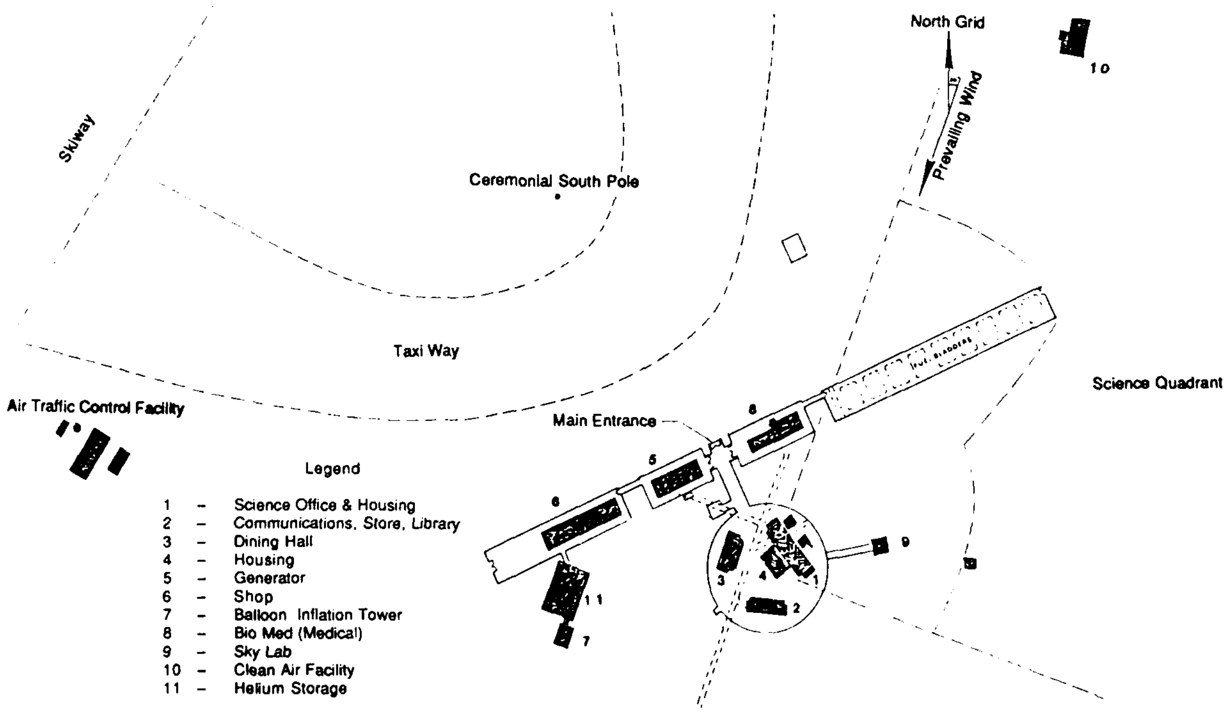


*Figure 18. Plot plan of South Pole Station, Antarctica.*

insulated pipe to a new outfall that is moved periodically. The current outfall is the third since the new station was put in operation in 1975.

As at Williams Field, this wastewater disposal practice has no adverse health or environmental impacts since the frozen material is permanently encapsulated in the Antarctic Ice Cap, at least until such time that glacial movement reaches an ice front on the ocean. The disposal practice can, however, have a significant thermal influence on the stability of adjacent structures.

The consolidation rate of snow is strongly dependent on temperature. Heat losses from the contained wastewater will cause a higher consolidation rate in the adjacent snowpack and therefore increased settlement of any structures supported by that snow. Studies in Greenland (Reed and Tobiasson 1966) indicated that the warming effect was not significant beyond 50 ft from the perimeter of the wastewater containment zone (see Fig. 16). The original outfall at Pole Station was constructed 160 ft beyond the foundations for the geodesic dome and should therefore not have any direct influence. The utility tunnel containing the heat-traced wastewater pipe does pass under the dome foundation, but the ambient air temperature in this tunnel is close to −55°F, so there should not be any adverse thermal influence from this source either.

With the information currently available, it is not possible to predict the lateral or vertical extent of these disposal pits at either Pole Station or Williams Field. The total annual wastewater flow at Pole Station is probably less than 250,000 gal. Because of the very low snow temperatures and relatively low wastewater flow it is very unlikely that the wastewater penetrates to the snow/ice transition point (about 360 ft deep), as is probably the case at Williams Field and at stations on the Greenland Ice Cap. It is far more likely that the wastewater freezes at a relatively shallow depth (less than 200 ft). This ice barrier then becomes the bottom of the new site and the containment zone moves upward from there. For example, a volume of snow 50 ft deep and 100 ft in diameter should have enough void space to contain the wastewater flow from Pole Station for three to four years.

It is strongly recommended that data be collected on the lateral and vertical extent of these wastewater containment zones at both Pole Station and Williams Field. The lateral extent can be determined with vertical thermocouple strings as employed in earlier studies in Greenland (Reed and Tobiasson 1966). The vertical dimension at the center can be determined with periodic visual observations at the outfall. Data from both locations would cover the range of temperature conditions to be expected and would provide a confident basis for design on other snowfields in Antarctica. The routine monitoring of the depth to the liquid surface in the central pool is important for design purposes and even more important for operational reasons. As the system ages the liquid surface will rise toward the outfall pipe and ultimately force the abandonment of that site. Data on the rate of rise will allow timely planning for outfall relocation, as compared to the present situation where there is no way to predict when replacement might be necessary.

### Solid waste management

Landfilling using trenches cut in the snow is the ultimate disposal pathway for trash and garbage at Pole Station. The kitchen at Pole Station has a compactor which is used for volume reduction of the kitchen wastes prior to disposal. A characterization study was not attempted at this station. A 1970 estimate indicated that the combined trash and garbage was about 5.7 lb/day per capita (Valentine 1972). Spent lubricants, tires, batteries, and similar materials are returned to McMurdo Station for removal from Antarctica.

## TEMPORARY FIELD CAMPS

These are generally seasonal activities, established to support research projects and occupied by a relatively small number of personnel. In essence, most of the waste management practices depend on the depth and permanence of the snow cover at the camp site. If the snow cover is deep (>10 ft) and perennial, then water supply and wastewater disposal can be managed as previously described for Williams Field and Pole Station. Most solid wastes can also be buried in pits if it is not practical to return them to McMurdo for disposal. Batteries, tires and lubricants are always returned to McMurdo for disposal.

If a permanent and deep snow cover does not exist at the site (e.g., Dry Valley), it may be necessary to return all waste materials to McMurdo for processing and disposal.

## CONCLUSIONS

1. The U.S. presence in Antarctica has undergone a very significant transition in the past decade. The former ad hoc expeditionary facilities and attitudes by some personnel have given way to a modern community on the shore of McMurdo Sound with complete utility services. There is a commitment by NSF and all the personnel involved to proper operation and maintenance and to environmental protection, and to cleanup of the residuals from the earlier expeditionary years. Many of the photographs and criticisms of U.S. operations that appear in the public press are in fact due to the last vestiges of these residuals and not to current operations.

2. The current wastewater disposal practice at McMurdo Station is within Treaty requirements and other applicable policy and guidance and should be continued, with the modifications recommended below. No adverse environmental impacts from this activity can be demonstrated.

3. Providing advanced, secondary or just a primary level of wastewater treatment at McMurdo Station would provide no significant environmental benefits but would increase the cost and complexity of operations very significantly. Disposal of sludges from these systems would be a problem. (Ocean disposal of biological sludges should be acceptable. However, if ocean disposal of both sludges and treated effluent is allowed, then why bother to treat the wastewater in the first place?)

4. Regardless of the level of wastewater treatment utilized, it will not be possible to restore the near-shore marine environment at McMurdo Station to pristine conditions as long as a community of up to 1000 persons is in active operation. In the present situation, with direct discharge of macerated wastewater diluted with brine, any impacts will be in the immediate vicinity of the outfall. This may stimulate, but not harm, growth in the local benthic community, but there should be no adverse impact on fish or other marine life or on the benthic community in the general waters of McMurdo Sound.

5. The current practice of burning of combustible wastes at Fortress Rock, McMurdo Station, is not the same as burning of trash and garbage at the now illegal open dumps in the United States. At McMurdo, a significant quantity of fuel oil is used to maintain a hot, "quick" fire. At the former dumps the fire smoldered, producing large quantities of smoke, particulate matter and odors. The smoke and particulates observed during the burn at McMurdo were minimal and probably represent less of an environmental impact than the engine exhaust and dust from normal station operations.

6. The use of more complex incinerator systems cannot be justified by the marginal environmental benefits that might be realized. The significant variations in population at McMurdo and the large contribution of combustible packing and construction wastes make design and operation of an incinerator system a difficult and expensive undertaking. Scott Base, which has an incinerator, still brings large-sized combustible wastes to McMurdo for burning at the Fortress Rock site.

7. The retrograde of baled combustible wastes or the recycle of other materials (aluminum cans) does not offer environmental, or other benefits, commensurate with the cost for implementation. On a world scale it makes little sense to transport baled waste thousands of miles for disposal in a landfill or by incineration when they can be managed directly and effectively at McMurdo Station.

8. The current combustible solid waste management practices at Fortress Rock should continue, with the modifications recommended below. The methods now in use are reliable, effective and result in minimal environmental impact.

9. The current practice of removing all batteries, tires and radioactive materials from Antarctica should be continued.

10. Most of the collected scrap metal was replaced on the ships and removed from Antarctica during the 1987–88 season. This retrograde activity is labor intensive and expensive and produces negligible environmental benefits. This practice can continue in future years, but strong consideration should be given to the managed disposal of these scrap metals to the deep waters of McMurdo Sound in accordance with Treaty provisions.

11. It is not practical to remove all of the buried scrap at the former Winter Quarters Bay dump site. Much of this area has been covered with fill material. This activity should be continued and completed. There should be no visible evidence of scrap materials along the McMurdo shoreline.

12. The cleanup activities underway at McMurdo Station should be continued and completed. This should include demolition of the old

buildings as they are no longer needed. A critical evaluation of the amount of old vehicles and equipment at McMurdo should be made to ensure that all are still needed in the active inventory. Those not needed should be removed. The amount of scrap metal requiring disposal should be reduced significantly when current construction and cleanup activities are completed.

13. The solid and liquid waste management practices currently used at Williams Field and Pole Station are reliable, effective, environmentally compatible and should be continued.

## RECOMMENDATIONS

1. The water usage rate at McMurdo Station is higher than expected if water conservation measures are fully employed. Efforts to reduce this excess water use should be undertaken. The installation and monitoring of water meters at selected locations should provide the data required. A more general study might consider the potential for further water conservation and reuse at all of the U.S. facilities in Antarctica.

2. The temporary wastewater discharges to McMurdo Sound should be terminated as soon as possible. All wastewater should be conveyed to the macerator building for treatment and discharge. This might require the use of a small grinder pump at the VXE-6 facility. An alternative might be the use of an incinerator toilet at this location.

3. Replacement of the present elevated wastewater outfall pipe with a buried and submerged discharge pipe is recommended. This will improve mixing and dispersion of the wastewater. The pipe must be protected from ice forces in the near-shore tidal transition zone. An alternate outfall location might be considered since construction through the existing fill material will be difficult.

4. A study to evaluate the potential for transmission of pathogenic organisms from the wastewater outfall to the water intake should be considered. Previous studies indicate minimal risk but this should be verified. If a hazard exists, the water supply can be chlorinated or otherwise disinfected. There is no reason to disinfect or otherwise treat the wastewater discharge.

5. A study should be undertaken to consider the beneficial use of the warm distillation brine now discharged directly with the wastewater. This might be for extraction of heat, or for fire protection, or for snow melting during the summer months. In most cases the brine, after beneficial use, could be returned to the wastewater line and still serve to dilute the wastes.

6. The basic management practices for combustible solid waste at McMurdo should be continued. However, there are several efforts that should be considered to improve efficiency and effectiveness of the operation:

a. The use of heavy-duty, commercial-grade trash compactors at selected locations would reduce the loose volume significantly and therefore also reduce the number of collection trips. As noted in the report, four locations at McMurdo accounted for 45% of the trash carried to the Fortress Rock site.

b. A heavy tractor (D6 or larger) is needed at the Fortress Rock site to push the accumulated wastes prior to burning to ensure effective combustion, and to then compact the ash and residues. The useful life of the site will be significantly reduced without the use of such equipment. Use of this equipment can be limited to the summer months when both population and construction activity are at their peak.

c. A fence is being erected to contain and confine blowing trash at the Fortress Rock site. Consideration should be given to extending the fence another 100 ft up Arrival Heights Road (beyond the final fence post observed in January 1988) to ensure containment.

d. Food and beverage cans are now taken to the Fortress Rock site along with the trash. Aluminum cans are consumed in the heat of the controlled burn but steel cans are not. It would have a minimal impact on the useful life of the site, but these steel cans could be crushed, baled and disposed of with the other scrap metal from McMurdo.

e. Most of the Dumpster trash containers scattered around McMurdo have no covers. A heavy duty wire mesh cover should be installed to prevent access by Skua gulls and to prevent escape of blowing trash.

7. Strong consideration should be given to the managed disposal of scrap metal to the deep waters of McMurdo Sound, as described in detail

in the text of this report. The earlier practice of disposal of all solid wastes to the annual sea ice surface in hopes it would be carried away should not be restored. Most of the objections regarding ocean disposal derive from the unsightly appearance of these dumps and on speculation, rather than fact, as to their impact on the marine environment. Disposal of clean scrap metal to deep water is permitted by the treaty and would have minimal impact on the environment.

8. The wastewater disposal methods used at Williams Field, Pole Station and other temporary inland camps are safe, reliable and environmentally compatible. As described in the text of this report, a study should be undertaken to define the snow containment zone for the discharges at both Pole Station and Williams Field. The results are needed to ensure successful operation and planning for future facilities.

## LITERATURE CITED


**Barnes, J. N., P. J. Lipperman and K. Rigg** (1987) Waste management in Antarctica. Washington, D.C.: The Antarctic Project.

**Bascom, W.** (1982) The effects of waste disposal on the coastal waters of southern California. *Environmental Science and Technology*, **16**(4):232.

**Clark, L. K. and G. Groff** (1962) Sanitary waste disposal for navy camps in polar regions. U. S. Naval Civil Engineering Laboratory, Contract Report NBY-32205.

**Coffin, R. C.** (1961) Technical data from Deep Freeze I, II, and III Reports (1955 to 1958). U. S. Naval Civil Engineering Laboratory, Technical Report 155.

**Cosenza, J. P.** (1966) Technical data compiled from operational reports on Deep Freeze 61 through 65. U. S. Naval Civil Engineering Laboratory, Technical Report R-438.

**Dumanoski, D.** (1988) Pristine Antarctica? Not McMurdo. *Boston Globe*, p. 31, May 23.

**Govt. N. W. T.** (1981) Community water and sanitation services North West Territories. Yellowknife, N.W.T.: N.W. Territories, Dept. of Local Government.

**GTO** (1984) Guidelines for housing and human settlement, planning and design criteria in cold climates. Copenhagen, Denmark: World Health Organization, Regional Office for Europe.

**Gunnerson, C. G.** (Ed.), (1988) Wastewater management for coastal cities. Washington, D.C.: World Bank Technical Paper no. 17, UNDP Rpt. no. 8.

**Holmes & Narver** (1979) Long range development plan—Volume II. McMurdo Station. Holmes & Narver Inc.

**Mitchell, B.** (1988) Undermining Antarctica. *Technology Review*, **91**(2):48–57.

**O'Connell, T. J. and S. A. Zaidi** (1979) Open pit incinerator—A technology demonstration project. Edmonton, Alberta: Environmental Protection Service, Report EPS 4-NW-79-2.

**Parker, B. C., M. A. McWhinnie, D. Elliot, S. C. Reed and R.H. Rutford** (1978) Ross Ice Shelf project environmental impact statement. In: *Environmental Impact in Antarctica*. Blacksburg, Virginia: VPI.

**Raytheon Inc.** (1986) The report on the McMurdo Station water quality study. Middletown, Rhode Island: Raytheon Service Co., Oceanographic Services.

**Reed, S. C., J. R. Bouzoun and W. Tobiasson** (1985) Water supply and waste disposal on permanent snowfields. *Canadian Journal of Civil Engineering*, **12**(2):344–350.

**Reed, S.C., W. Tobiasson** (1966) Wastewater disposal and microbial activity at ice cap facilities. *Journal of the Water Pollution Control Federation*, **40**(12):2013–2020.

**Smith, D.** (Ed.) (1986) Cold climate utilities manual. Montreal, Quebec: Canadian Society for Civil Engineering.

**Valentine, B. W.** (1972) Self-contained sanitation systems for 2- to 15-man polar facilities. U. S. Naval Civil Engineering Laboratory, Technical Report R 759.

**Waldrip, D. B.** (1984) The McMurdo Station sanitary landfill evaluation and recommendations report. Paramus, New Jersey: ITT Antarctic Services.

**Ward, C. J.** (1979) Feasibility of baling and incineration of solid waste at McMurdo Station, Antarctica. U. S. Civil Engineering Laboratory, Report M-64-79-10.

## APPENDIX A: ANCILLARY INFORMATION

### List of communities in the United States with a permit or tentative approval from the U.S. Environmental Protection Agency to discharge wastewater, equivalent in character to that at McMurdo Station, to the ocean

In addition to the 37 listed below, there are an additional 12 with permits in American Samoa, Guam and the Trust Territories.

*Maine*
Bayville Village, Boothbay Harbor, Bucksport, Eastport, Jonesport, Kennebunkport, Lubec, Milbridge, Newton Highlands, North Haven, Northport Village, Portland (Peaks Island), Rockport, Searsport, Wintersport.

*Massachusetts*
Gloucester, Gosnold.

*New Hampshire*
Portsmouth, Rye.

*California*
Encina (Leucadia/Carlsbad), Goleta, Morro Bay, San Francisco, Santa Cruz, Watsonville.

*Hawaii*
Honouliuli, Kailua/Kaneohe, Sand Island (all in Honolulu area).

*Alaska*
Anchorage, Haines, Ketchikan, Pelican, Petersburg, Sitka, Skagway, Whittier, Wrangell.

### Calculations related to estimates of combustible solid waste production

Figures 10 and 11 show the combustible wastes accumulated at the Fortress Rock site during a 12-day period (2–14 January 1988). Due to the irregular shape of the pile it was divided into six sections and the volume of each was measured with a hand level and tape. The resulting calculations produce:

| | | | |
|---|---|---|---|
| 1. | 4 x 30 x 75 | = | 9,000 $ft^3$ |
| 2. | 5.6 x 68 x 70 | = | 26,656 |
| 3. | 4.4 x 50 x 60 | = | 13,200 |
| 4. | 2 x 25 x 20/2 | = | 500 |
| 5. | 5.6 x 15 x 70/2 | = | 2,940 |
| 6. | 5.6 x 15 x 70/2 | = | 2,940 |
| | Total | = | 55,236 $ft^3$ |

Daily production = 55,236 $ft^3$/12 day
= 4603 $ft^3$/day.

Per capita production:
4603 $ft^3$/977 people = 4.7 $ft^3$/day.

The Dumpster containers hold about 250 $ft^3$ each and appeared to be about 75% full on average. There were 230 Dumpster loads delivered to Fortress Rock during the 12-day period. Therefore, wastes from other sources would be:

(230 loads) (250 $ft^3$ each) (0.75) = 43,125 $ft^3$
(55,236 – 43,125)/55,236 = 22%, use 20%.

The contents of several Dumpsters from several sources (Galley, Bldg. 204/205, Acey Deucy, Dorm 201/202, etc.) were individually weighed with a hand-held spring balance.

The contents of one of the daily Dumpster loads from Building 204/205, for example, was 251 lb of waste in plastic bags and 17 lb of empty cardboard boxes—a total of 268 lb. The population of the two buildings during this period was 91 persons. The per capita waste production would therefore be:

(268 lb/day)/(91 people) = 2.9 lb/day, use 3 lb/day.

The average weight of all Dumpster contents measured was 197 lb each, which gives a total per capita production of:

(230 loads) (197 lb/load)/(12 day) (977 people) =
3.9 lb/day per capita.

As noted above, 80% of waste was delivered to Fortress Rock in Dumpsters; the remainder came from other sources. The total per capita daily contribution would be:

(3.9 lb/day)/(0.80) = 4.8 lb/day per capita.

On this basis the total daily contribution would be:

(4.8 lb/day) (977 people) = 4690 lb/day.

Also, as noted above, living spaces contribute about 3 lb/day per capita for a total of 2931 lb/day. So, the wastes from other sources (galley, shops, offices, construction, etc.) is:

4690 lb/day – 2931 lb/day = 1759 lb/day,
use 1800 lb/day.

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